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Canaigre

A Potential Domestic Source of Tannin

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CONTENTS

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CANAIGRE . . .

A Potential Domestic Source of Tannin

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INTRODUCTION

Vegetable tannin is of considerable importance in the economy and defense of the United States because of the vital role that it plays in the manufacture of leather goods. Tannin is used also as a mud conditioner in the drilling of oil wells, in boiler compounds, in the processing of certain kinds of ores, and for other industrial processes. No satisfactory synthetic substitutes for naturally produced tannin have been developed.

Around 1925 the United States produced more than half of the vegetable tannin that it consumed in leather manufacture. Most of it was extracted from wood of the American chestnut tree and from oak bark. These sources now have been almost exhausted. Except for a very small quantity of tannin extracted from hemlock bark in the Pacific Northwest, the industrial needs of the United States for tannin must now be supplied through imports from foreign sources.

Approximately 80 percent of the tannin used in the United States is imported from Argentina and Paraguay, where it is extracted from the heartwood of mature wild quebracho trees. Another 15 percent of tannin imports is extracted from wattle bark produced under cultivation in South Africa and East Africa. The balance of our tannin imports include extracts of chestnut, mangrove, valonia, myrabolans, eucalyptus, and tara. Heavy exploitation of quebracho timber in South America is slowly depleting these natural reserves, which are not expected to last more than 30 to 50 years at the present rate of utilization. Attempts to reestablish stands of quebracho have been unsuccessful.

In the United States there has been growing concern over the national and world tannin situation. Studies were conducted just before and during World War II for the purpose of developing new domestic sources of tannin, which under existing world conditions was nationally of great strategic importance. Numerous species of native and introduced plants were surveyed for their tannin-producing possibilities. These included canaigre, sumac,

hemlock, spruce, pine, red mangrove, scrub oak, tara, wattle, and pecan shells. Canaigre shows the brightest prospect of filling the need for a domestic source of vegetable tannin.

DISTRIBUTION AND DESCRIPTION

Canaigre is indigenous throughout much of the Southwestern United States and Northern Mexico (fig. 1). At the lower elevations in Texas, New Mexico, Arizona, and California, the plant is mainly distributed in sandy soil along natural drainageways, where

FIGURE 1.—Locations where canaigre has been observed growing wild. Roots collected at most of these points have been grown for observation at Mesa, Ariz.

it may receive some supplemental moisture from periodic stream flooding. At higher elevations where rainfall is more abundant, it may be found also in windblown sand deposits and even in heavier textured soils. The plant occurs at elevations ranging from near sea level in Texas and California to over 7,000 feet in southern Wyoming.

Canaigre (*Rumex hymenosepalus* Torr.), the roots of which are rich in tannin, is closely related to the several common dock species that are weeds on farmland in much of the United States. Other common names for canaigre are sour dock, wild rhubarb, Indian pieplant, and tanners' dock.

Canaigre is a perennial herb; the tops die back to the root crowns at the end of each growing season. During the following season

new top growth arises from crowns of the old roots, which multiply like dahlia roots, but unlike dahlia, they remain alive in the soil for a number of years. The tops resemble those of certain other species of dock, having long, lance-shaped leaves with thick, juicy midribs and short, thick petioles (fig. 2). Leaf blades are entire, usually with wavy or crinkled margins. Flower stalks are thick and succulent, often growing to a height of 2 to 3 feet or more when soil moisture is adequate. The inflorescence is a long, thick, compound spike. The inconspicuous epetalous flowers are borne in

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FIGURE 2.—A single canaigre plant growing in April in a crossing block at Mesa, Ariz. Plant is 2½ feet tall. Seed is maturing and beginning to shatter.

small clusters on slender, filamentous peduncles. The flowers are perfect but protogynous, since the feathery white stigmas are receptive and protrude from between the enclosing three sepals several days before pollen from the same flower is shed. Fertilization is achieved through wind pollination. The upright seedstalks usually have elongated to only half or two-thirds of their ultimate height by the time blooming is completed. Thereafter the sepals enlarge greatly, usually changing color from green to bright shades of yellow, orange, pink, or red and are quite conspicuous. At seed maturity the enclosing sepals or valves turn brown, usually are deeply cordate, and 10 mm. or more in width (fig. 3). The valves are persistent on the three-sided shiny brown seeds. Seed production usually is scanty or entirely lacking under wild conditions, often due to inadequate moisture.

Unlike other species of dock, the fleshy roots of canaigre are tuberous and produced in clusters (fig. 4) that are easily separated into individual roots, which may be planted for vegetative reproduction. Externally the roots are very dark in color, almost black at maturity. The buds from which new growth arises are concentrated at the crown end of the root and only one seed piece is normally cut from a single root. Much variation exists between different wild sorts in regard to the size and shape of roots when grown under irrigation. Root shape ranges from that resembling short, thick carrots or sweetpotatoes to a long, slender, branching habit of growth. A wide range of variation in internal root color and chemical constitution also exists between wild types. New growth is usually white like the flesh of a radish. At maturity, however, the color may range from a light cream through shades of

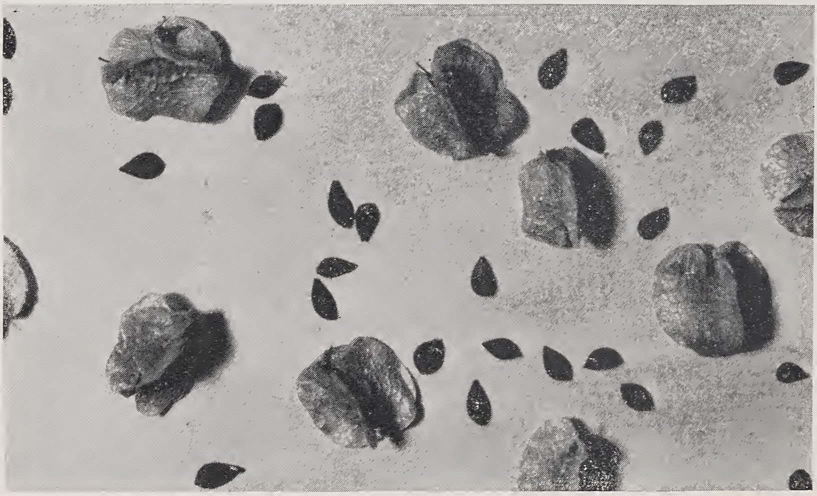

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FIGURE 3.—Mature canaigre seeds before and after being hulled. Paperlike wings, or sepals, that adhere firmly to bases of the 3-sided seeds can be removed easily by means of a special huller.

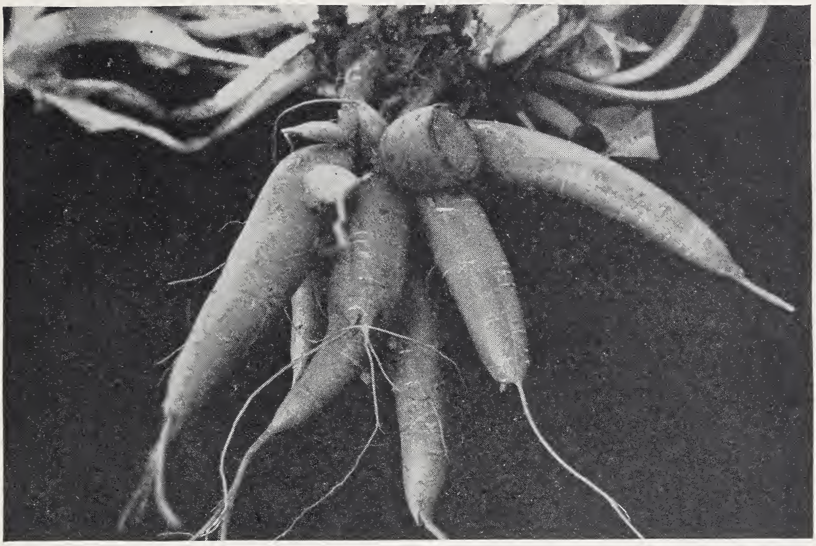

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FIGURE 4.—Roots of a single plant (variety, Salt River) are about two-thirds mature size in early April. Parent crown, or seed piece, from which plant grew was planted in October.

yellow and pink to a brownish orange and with concentric zones of color of different hues.

Tannin content of the roots may vary also, from less than 4 percent to as much as 42 percent in roots 1 year old. Tannin content tends to increase with age of roots, so that roots 4 years old or older may have up to 7 percent greater tannin content, on a dry-weight basis, than roots 1 year old. The tannin content of wild roots diminishes greatly as the northern and eastern limits of its habitat are approached. The highest tannin content of roots is found in material originally collected along the Salt and Gila Rivers in central Arizona (fig. 5).

In the more arid and warmer areas of its habitat, top growth will appear late in the fall or early winter if there is sufficient moisture available. When soil moisture is lacking in the fall, top growth is delayed and may not appear at all if winter rainfall is very low. At higher elevations, especially in the northern limits of its habitat, canaigre does not produce new tops until snow is gone and warm spring weather appears.

HISTORICAL

Early settlers in the Southwest found the Mexicans and Indians using canaigre for tanning hides, as a dye, and as a medicine. The succulent leaf petioles were sometimes boiled or roasted and eaten as greens. The earliest recorded account of canaigre followed the

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FIGURE 5.—Increase plantings of canaigre near Queen Creek, Ariz., in 1957. The Sacaton variety, two rows at left, have more erect habit of growth than Salt River variety on right. Both varieties are excellent sources of breeding material.

collection of botanical specimens near El Paso, Tex., by Torrey (*23*)[1] in 1859, who named it *Rumex hymenosepalus*.

The first reports of the chemical composition of the roots showed a tannin content of 23 to 26 percent (*24*, *25*). Attempts to export wild fresh roots in 1882 failed (*4*), but dried roots were exported successfully in 1887 (*14*).

Extraction plants were built at Tucson, Ariz.; Deming, N. Mex.; Rialto, Calif.; and San Antonio, Tex., between 1886 and 1892. By 1893, Eitner (*8*, *9*) had reported canaigre to be a good source of tanning material. Early attempts to grow the crop commercially have been reported in a number of publications (*3*, *10*, *15*, *18*). Interest in canaigre declined about 1900, because of competition with cheap tanning material from other sources.

RESEARCH AND DEVELOPMENT PROGRAM

The present research and development program was initiated in 1937. The Crops Research Division is responsible for all cultural and breeding studies. The Eastern Utilization Research and Development Division performs the analytical work on samples from the cultural and breeding studies, conducts extraction studies, and evaluates leather tanned with canaigre extract.

Cultural work during the period 1937–47 was concerned with (1) progeny studies of wild roots, (2) cultural requirements, and (3) regional adaptation.

Testing of progenies from wild roots selected from a wide range of natural conditions indicated the highly variable nature of the plant. Selection within progenies from various geographic sources

[1] Italic numbers in parentheses refer to Literature Cited, p. 31.

has provided strains with superior type, yield, tannin content, and purity.

The natural habitat of canaigre is limited to the arid and semiarid regions of Southwestern United States and Northern Mexico. Regional trials extending from Florida, Georgia, and South Carolina, west to California, have shown the plant grows best in its natural range from central Texas to southern California. Considerable information has been accumulated about the best cultural methods to produce the crop in this area.

The development of tanning extracts from canaigre, their effectiveness in the manufacture of leather, and wearing qualities of products made from canaigre-tanned leather, have been reported by the Eastern Utilization Research and Development Division (*1*, *2*, *5*, *6*, *7*, *11*, *12*, *13*, *16*, *17*, *19*, *20*, *21*, *22*).

CULTURAL INVESTIGATIONS

Since the initiation of the current canaigre research program in 1937, there has been no commercial production of the crop. Field investigations have been conducted almost entirely at State and Federal experiment stations and on privately owned land leased for the purpose by the Federal Government. Consequently, the research program has not had the benefit of observing the crop being grown on large acreages by many growers and under a broad variety of environmental conditions and production methods. Nevertheless, canaigre has been grown experimentally in many locations and under a fairly wide range of conditions in the Southwest. And, while the information developed thus far on the various phases of canaigre culture is by no means complete, it should provide a sound basis for the rapid development of the industry in the event of a national emergency or a normal peacetime demand for domestic production of tannin. The different aspects of crop production research on canaigre are discussed below.

Soil Requirements

Canaigre, growing in the wild, usually is found in sandy to sandy loam soils. Instances have been observed, however, of canaigre growing in relatively heavy soils in Wyoming, Colorado, Utah, and Arizona. In these cases roots have been very low in tannin content, and when grown under cultivation are unsuitable for use in a crop development program. Every wild collection having a tannin content of 25 percent or higher when grown under cultivation, was originally found growing in light-textured alluvial or wind-deposited soil.

Very few attempts have been made to grow canaigre experimentally in heavy soils. An irrigated planting in 1937 on heavy Gila clay soil at the Agronomy Farm at State College, N. Mex., gave poor results, due to difficulty in maintaining clean cultivation and to low yields of small roots. Plantings made the same season on heavy soils at several points in Texas gave similar results. Consequently, it was concluded that canaigre is not adapted to heavy

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soils. Thereafter, canaigre plantings were confined almost entirely to the lighter textured soils. In 1950, however, a small isolated planting of the A10 variety was made for pure seed production on relatively heavy Laveen clay loam soil at the University Experiment Farm at Mesa, Ariz. Root yield estimates were not made, but roots of good size were produced. The crop was dug by hand but could have been dug easily with machinery. Potatoes have been harvested from the same soil with modern potato-harvesting machinery. Attempts are being made currently to evaluate the suitability of heavy soils for canaigre production.

The soils that appear to be the best adapted to canaigre under cultivation are deep, well-drained and well-aerated sandy loams having a good moisture-holding capacity and a low alkali content. Experimental plantings on soils of this nature in the Queen Creek district of Arizona have produced root yields ranging from 15 to more than 20 tons per acre in a single season under favorable cultural conditions. In several instances where canaigre was grown on tight soils, where water penetration was difficult and salt content high, plant growth was poor and root yields very low. The effects of high soil-salt content and of abnormal soil pH levels on the tannin content of canaigre roots are not known.

Propagating Materials

Canaigre may be grown either from roots or from seed. The earliest efforts to grow canaigre under cultivation were made by planting whole roots gathered from wild plants, because that was the only propagating material available. Wild plants, due to the conditions of limited moisture under which they exist, usually produce small roots and little, if any, seed except in unusually wet years. Canaigre grown under irrigation, however, produces much larger roots, which are unsuitable for planting whole with potato-planting machinery because of their size. It was found that by planting a short section from the crown end of the root the yield of new roots was as great as when whole roots were planted.

Canaigre plantings that were irrigated also produce considerable quantities of seed. Early reports had indicated that canaigre seed was very low in viability. This was refuted later, however, by results of germination tests and by the fact that seedling volunteers appeared in large numbers during the season following harvest of crown-planted canaigre in 1941. The results of several seasons of testing thereafter appeared to indicate that canaigre could be grown successfully from seed. Since that time experimental seed plantings of canaigre have been made at 21 locations, totaling more than 100 acres.

Conditions for growing the crop from seed are more exacting than from crowns. Seedbed preparation for seed planting is about the same as for such vegetable crops as lettuce and carrots. Careful leveling of the field is required to insure uniform distribution of irrigation water. Seed is drilled on the shoulders of low, raised beds separated by shallow irrigation furrows. The first irrigation after planting is of critical importance in obtaining a satisfactory stand. If water is allowed to flow over the surface of the soil covering the seed, crusting of the surface as it dries out may pre-

vent the emergence of seedlings. An uneven or light irrigation will result in inadequate wetting of soil around the seed, resulting in poor germination and unsatisfactory stands. The small, slow-growing seedlings are vulnerable to disease and insect attacks and to wind-driven sand, which can destroy them quickly.

Fewer hazards are encountered in growing the crop from crowns. Crown-grown canaigre will tolerate much rougher preliminary field leveling and seedbed preparation. A satisfactory first irrigation after planting is much easier to achieve for crowns than for seed. Flooding of the soil covering the crowns does not prevent the emergence of top growth through a hard crust. Instances have been observed where new top growth burst through hard-packed surfaces of roadways and asphalt pavement. Although insects in several cases have destroyed new top growth arising from crowns, the plants suffered only temporary setbacks. New shoots soon arose from the crowns and growth was resumed.

Propagation from crowns is the only feasible method of growing canaigre at the present stage in the development of the crop. A wide range of variability in all measurable characters is found within the species and to some extent even among individual plants of a given wild "variety," or ecotype. Vegetative propagation thus permits the development of very uniform varieties simply by increasing the roots from selected plants, as in the case of potatoes. The cost of planting materials and of planting is considerably higher for crowns than for seed. But this is compensated for by the lower cost of seedbed preparation and the greater certainty of obtaining good stands. Higher yields of roots with a higher tannin content and extract purity generally have been obtained when crowns were planted (table 1). However, the development of uniform, high-producing, high-tannin varieties that can be grown sat-

TABLE 1.—*Comparison of root yield and percentages of tannin content and of extract purity between seed- and crown-planted unselected Salt River canaigre when grown 2 seasons before harvest and when grown as two 1-year crops on the same land, Queen Creek, Ariz., 1955–57*

Planting material	Years to harvest	Harvest date	Root yield [1]	Tannin content (dry-weight basis)	Extract purity [2]
			Tons/acre	*Percent*	*Percent*
Seed	1	1956	14. 1	30. 8	64. 3
	1	1957	10. 5	27. 7	59. 4
Do	2	1957	23. 4	32. 6	63. 5
Crowns	1	1956	16. 9	35. 6	67. 7
	1	1957	13. 4	36. 6	66. 7
Do	2	1957	29. 5	36. 9	67. 1

[1] Values given are means of 5 replicates and are calculated from yield plots 0.0076 acre in size. Total root yield for 1956 and 1957 is 24.4 tons for seed-planted canaigre; 30.3 tons for crown-planted canaigre.

[2] $\frac{\text{Tannin}}{\text{Total soluble solids}} \times 100 = \text{percent purity.}$

isfactorily from seed is an ultimate objective of the canaigre breeding program. It is believed that seed propagation eventually may be a more economical method of production and will give the prospective canaigre industry greater flexibility for rapid expansion and sudden cutbacks in acreage to meet fluctuations in the demand of industry for the extract.

Meanwhile, a small stockpile of seed, consisting of several wild, unselected varieties sufficient to plant up to 300 acres, has been accumulated. Owing to the variable nature of the material, it is not suitable for use in a normal peacetime expansion program. However, should a national emergency arise, it would be possible to expand acreage sufficiently with the available seed to meet national tannin requirements within 3 to 5 years. Production of superior varieties through vegetative propagation would be expected to replace seed-planted acreage as fast as crown-planting stock could be increased.

Date of Planting

The optimum date for planting canaigre, either from seed or from crowns, appears to be during the last week in October in southern Arizona. In a series of replicated trials from 1952 to 1957, canaigre crowns of the Salt River variety were planted at dates ranging from early September to late December. Results consistently indicated that root yields were reduced progressively with each successively later date of planting after October 31. In several tests, the yield reductions were in the order of 1 ton per acre for each additional delay of 1 week. Planting earlier than the last week of October produced somewhat earlier fall growth and stimulated spring top growth and seed production, but the resulting root yields were not significantly higher (table 2). Similar results were observed for both seed and crown planting. There was some

Table 2.—*Variation in growth behavior, root yield, and root characteristics of Salt River canaigre roots planted at 5 dates in 1955 near Queen Creek, Ariz. Values shown are means of 4 replicates*

Date planted	Growth ratings [1]			Root yield	Dry matter	Tannin content (dry-wt. basis)	Extract purity [2]
	Tops, May 7	Fruiting, May 7	Decline, June 4				
				Tons/acre	*Pct.*	*Pct.*	*Pct.*
September 29	9	8	10	17.9	28.6	35.4	67.5
October 13	7	8	9	17.4	30.4	35.3	68.3
October 27	6	6	7	17.1	29.6	35.5	68.8
November 10	5	4	6	14.9	31.1	35.1	69.5
November 25	3	2	5	11.9	31.6	34.8	70.5

[1] Growth ratings are from 1 (low) to 10 (high); a decline rating of 10 indicates complete dormancy, 5 indicates 50 percent of leaf area is dried up.

[2] $\frac{\text{Tannin}}{\text{Total soluble solids}} \times 100 = \text{percent purity}$.

indication that differences may exist between varieties in their response to date of planting. In one crown-planted trial that included both Salt River and A10 varieties, the break in the yield pattern of A10 occurred between the October 14 and October 28 plantings while that of Salt River occurred between the October 28 and November 12 plantings.

Row Spacing and Planting Rates

The cultural and harvesting requirements of canaigre indicate the necessity for growing it as a row crop like potatoes, beets, and other root crops. When grown from crowns, the closest practical row spacing is about 30 inches. Rows 20 inches apart increased yields up to 10 percent or more as compared with 30-inch rows, but the narrower width interfered with cultivation and furrow irrigation of the crop. Root yields were reduced as the distance between rows was increased from 30 inches, even though the plant population per unit of area was kept constant.

Several experiments were conducted in order to determine the effect of spacing crowns at various intervals within rows. The results of four trials are summarized in table 3. As the data indicate, yields increased as the rate of planting increased. And it would appear that still greater yields might be expected to result from even higher planting rates. However, it was observed that as the planting rate was increased, the size and number of roots produced per hill were reduced, and the surviving seed crowns constituted an increasing proportion of the total crop yield. On the basis of the limited information available, it appears that the most effective returns under the conditions of these experiments might be obtained at a spacing of 5 to 6 inches between crowns. Further work is needed on the problem of crown-planting rates under a variety of conditions.

Various methods of growing canaigre from seed have been tested. The best results have followed the use of methods similar to those

TABLE 3.—*Summary of 4 experiments conducted near Queen Creek, Ariz., showing variations in total root yields resulting from differences in rate of planting in 30-inch rows, 1953–57*

Trials		Yields from crown spacing within row of—							Least significant difference
Variety	Planted	12 in.	10.5 in.	9 in.	7.5 in.	6 in.	4.5 in.	3 in.	
		Tons/acre	*Tons/acre*	*Tons/acre*	*Tons/acre*	*Tons/acre*	*Tons/acre*	*Tons/acre*	
Wilcox	11/2/53	6. 4	-----	7. 4	-----	9. 5	-----	12. 5	1. 23
Salt River	10/8/54	10. 4	-----	16. 2	-----	18. 4	-----	19. 0	3. 0
Do	[1] 9/25 to 11/24/55	12. 8	-----	17. 1	-----	17. 7	-----	22. 9	3. 2
Do	10/24/56	13. 6	12. 4	13. 0	13. 8	15. 6	18. 0	-----	2. 4

[1] In a date X rate of planting trial with 5 dates of planting, there was a nonsignificant D X R interaction.

employed in growing lettuce under irrigation in Arizona. After the field has been plowed and floated, it is furrowed out to a depth of 6 to 8 inches with lister shovels set 40 inches apart. Seed is then planted with a bed-shaper planter, drilling the seed in 2 rows 12 or 13 inches apart on each bed. Irrigation water is applied in the furrows separating the beds until the beds are saturated, or "blacked out." Two irrigations may be required to establish a stand if the weather is hot and dry or if the soil is very light and quickly dries out. It is important to avoid letting irrigation water flood over the tops of seed rows in order to prevent crusting of the soil, which interferes with emergence of seedlings.

Bed spacings greater than 40 inches are unsatisfactory, because tractor equipment generally is not geared to such wide settings and root yields are reduced. Attempts were made to grow canaigre on beds narrower than 40 inches but with little success. The narrower spacings interfered with effective cultivation when 2 rows per bed were planted, and yields were greatly reduced when a single row was planted on each bed.

In repeated trials, seedlings have been thinned to various plant spacings in an effort to determine the effect on yield. Maximum yields of harvestable roots usually have occurred where 4 to 6 plants remained per linear foot of row. Closer spacing increases the number of small roots without actually increasing yields. The very small roots usually fall through the digger apron and escape harvest. Increasing the spacing to more than 3 inches between plants results in larger roots but reduces the total yield.

There are between 50 and 60 thousand seeds per pound of threshed, recleaned canaigre seed, depending upon variety. A planting rate of 3 pounds per acre, using seed testing 85 to 90 percent germination, will provide 5 to 6 viable seeds per foot of row. Under proper planting conditions practically every viable seed may be expected to grow. Thinning the crop after the stand is established is not economically feasible, since canaigre is not likely to be a high-value crop like lettuce and certain other vegetable crops. Consequently, it is important to obtain a uniform distribution of seed.

Depth of Planting

Differences in depth of planting crowns, down to about 8 inches, do not appear to affect canaigre root yields. However, new roots are initiated at the point where sprouts emerge from the seed piece and extend downward, fanning out at various angles from the crown. Therefore, in order to reduce to a minimum the amount of soil that must be handled by the digger at harvesttime, it is important to plant crowns as shallow as possible. Optimum depth of planting crowns for maximum yields and efficiency in harvesting appears to be 3 to 4 inches below the surface of the soil ridged up over the crowns. Shallower planting, especially early in the season, can result in the soil becoming too dry around the crown to permit sprouting and root formation. On the other hand, deep planting late in the season when soil temperatures are low appears to delay the emergence of top growth. Planting crowns at depths

greater than 8 inches results in a drop in yield due to a reduction in both size and number of roots.

In the wild and under cultivation, when the top growth produced by deeply placed roots dies back in the spring, the underground portion of the stem usually dies back also to a point 3 to 5 inches below the soil surface. Below that point the stem is quite fleshy and remains in a dormant condition during the summer. This dormant, fleshy stem closely resembles in color, texture, and tannin content the new roots produced by the parent crown. At intervals of 1½ to 2 inches along the underground stem, nodes occur from which arise fibrous roots. Each node also bears a dormant bud. Tuberous roots, also bearing crown buds, may be produced at one or more of these nodes. This fleshy, underground stem, when cut up into sections, each bearing one or more nodes, can be used as propagating material. When regrowth from undisturbed plants is resumed in the following season, the production of new roots is concentrated at or near the top of the fleshy underground stem. This probably is a manifestation of effort by the plant to establish a crown at a more optimum level in the soil.

Root yield and plant behavior appear to be unaffected by the axial position of the seed piece. When roots and crowns were planted with the buds pointing downward in the soil, growth and behavior of the plants were no different from plants arising from crowns planted in an upright position.

Under most conditions the optimum depth of planting for canaigre seed is about three-fourths inch. Good stands of plants have been observed to emerge from seeds planted to a depth of 2 inches, but only if planted in loose, friable soil that did not crust over following irrigation. At very shallow depths of planting, ¼ to ½ inch, the surface soil often dries out before the seed has sprouted. It is possible at times to plant in soil moist enough that an irrigation can be avoided after planting. Weather conditions in the Southwest during the canaigre planting season, however, usually are warm and dry. In order to obtain good germination it generally is necessary to irrigate at least once after planting and often two irrigations are required before seedlings emerge from the soil.

Crown Size

As in the case of potatoes, the size of the canaigre seed piece affects the yield of new roots. An early experiment led to the conclusion that the seed crowns should be cut at least 1½ inches long for satisfactory root yields. Results of subsequent experiments show that yields of new roots tend to increase with increasing weight of the seed piece and that the increase in yield is due mainly to an increase in the number of roots produced rather than to an increase in root size. However, there does not appear to be much advantage in planting crowns greater than 2 ounces in weight, approximately 2 inches long and 1½ inches in diameter. Further increases in crown size result in only slightly higher yields of new roots, whereas mechanical planting problems multiply. When planted at a 9-inch spacing in 30-inch rows, 23,226 crowns are required to plant 1 acre. Crowns averaging 1 ounce each, sufficient

to plant 1 acre at that spacing, weigh approximately 1,500 pounds.

Under commercial production crowns of all plantable sizes probably will have to be used in order to maintain the required acreage. Roots grown 1 year from crowns vary in size within the same hill from less than ½ inch in diameter to as much as 2½ inches or more. Crowns small enough to plant with machinery cannot be cut from the larger roots, and the smallest roots are unsatisfactory also as planting stock.

Seed crowns usually remain alive in the soil throughout the year and are harvested with the roots, making a substantial contribution to the total yield. Most crowns increase in weight during the growing season, due to the laying down of new tissue under the bark. Small crowns increase in weight proportionally much more than large crowns do. In one experiment crowns weighing 10 grams at planting time had increased to over 65 grams, an average increase of 553 percent by the end of the growing season. At the same time crowns that weighed 60 grams each at planting time averaged only 85 grams at harvest for an increase of 41 percent (table 4). There is a tendency for seed crowns to put forth extensions or branches from the cut surface. These branches are never complete tuberous roots, since they do not possess buds other than those that occur at the apex of the old crown from which they arise. This tendency varies under different environmental conditions and in different varieties. Root branching from the old crowns appears to be much more frequent in heavy soils than in light sandy soils.

TABLE 4.—*Effect of seed-piece size on root yield of canaigre harvested at Queen Creek, Ariz., in 1957. Length of seed piece 2 inches. Each plot included 10 hills spaced 12 inches apart in a single row*

Original weight of seed crowns (grams)	Mean [1] total plot yield	Original crown weight, as percent of total yield	Seed crown weight increase [2]	Large roots [3]		Weight small roots, as percent of total yield
				Per plot	Mean weight	
	Pounds		*Percent*	*Number*	*Pounds*	
160	26. 5	13	22	48	0. 42	6. 2
140	24. 3	13	12	55	. 35	3. 5
120	22. 5	12	25	44	. 42	2. 6
100	22. 3	10	41	39	. 47	3. 0
80	26. 0	8	20	54	. 43	2. 6
60	20. 5	4	41	37	. 49	1. 3
40	21. 7	4	84	40	. 50	1. 0
30	21. 2	3	150	28	. 70	. 3
20	20. 1	2	254	29	. 63	. 8
15	16. 6	2	203	26	. 60	. 7
10	12. 9	2	563	24	. 48	. 4

[1] Values given are means of 3 replications and include the weights of surviving seed pieces. Least mean difference necessary for significance at 5-percent level is 7.1 lb.

[2] Weight increase is due to radial thickening of tissue and in some cases to production of enlarged projections or branches.

[3] Roots 1 inch or larger in diameter. Those measuring less than 1 inch in diameter averaged only 3 percent of the total yield.

Because of the ability of seed pieces to live over from one season to the next, it is possible to replant old crowns for still another year's production. However, it has been observed that the development of new top growth from old crowns is slightly later than from new crowns. Old crowns usually are somewhat more difficult to plant mechanically than fresh crowns because of their increase in size and because of their harder exterior. The picker-type planter has greater difficulty in picking up old crowns and leaves more skips in the row than with newly cut crowns.

It is possible to split large crowns radially into several seed pieces, each bearing buds. This procedure is useful in increasing vegetative lines to the maximum degree; however, it is not practical for ordinary production. Most roots produce buds in a very restricted area of the crown so that they cannot be split without endangering viability of the pieces, which dry out rapidly, owing to the increased cut-surface area.

Planting Machinery and Methods

Canaigre is adaptable to crown planting with the same machinery as that used for potatoes. A modern 2-row picker-type planter, requiring a 2-man crew, including the tractor driver, has been used successfully to plant canaigre. That type of planter is especially applicable to field-scale planting because of the speed and efficiency with which it can be operated—2 acres per hour or better—and because of the wide range of crown size that it will handle without becoming jammed. Most of the experimental canaigre acreage grown from crowns, however, has been planted with a standard 2-row plate-type potato planter requiring a 3-man crew (fig. 6). Although this machine is less efficient—planting a maximum of less than 1 acre per hour—it lends itself particularly well to small-plot work and to controlled spacings of crowns in the rows. The picker-type planter sometimes leaves very short skips or unplanted sections of row. This may not be serious in a field-scale planting, but it cannot be tolerated in small-plot work.

Both machines open shallow, narrow furrows into which the seed pieces are dropped at regular intervals. A pair of disk hillers, mounted just back of each planter shoe, ridges the soil over the crowns, leaving wide furrows between the rows for irrigation. Band application of commercial fertilizers is possible with the aid of fertilizer attachments on both types of planters.

Canaigre seed also is adaptable to planting with existing vegetable planting equipment. Excellent results have been obtained in experimental trials with a tractor-mounted bed-shaper that forms the tops and sloping sides of two beds as it moves along. Four cylinder-type garden planter units, mounted on top of the shaper, meter the seed from the hoppers at a uniform rate. Planter shoes are rigidly mounted at the rear of the shaper, depositing the seed in drills at a uniform depth in the soil. Packer wheels, loosely mounted at the rear of the shoes, firm the soil around the seed. Most commercial planters used for lettuce and carrots and other bed-planted vegetables can be adjusted readily for canaigre seed.

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FIGURE 6.—A standard make of plate-type potato planter used for experimental plantings of canaigre. A heavier, more recent model planter of the picker type is much more efficient for field-scale plantings, but it is not adaptable to small-plot work.

Irrigation

Canaigre is capable of surviving on relatively little soil moisture, both under wild conditions and as a cultivated plant. Attempts to grow canaigre without irrigation, however, generally have met with little success. Early experiments indicated that while the aggregate moisture requirements of the crop may be low, the proper distribution of irrigation during the growing season probably is important.

In order to develop information on this point, a series of four irrigation trials, each of a single season's duration, were conducted at Queen Creek, Ariz., during the period 1953–57, using crown-planting material of unselected locally adapted varieties. The first two trials each included eight treatments, or arbitrarily selected irrigation schedules, designed to determine the effect on yield due to different levels of irrigation and to withholding irrigation for certain periods of the growing season.

As might be expected, the results shown in table 5 indicate that root yields increased with the number of irrigations. It is apparent, also, that when irrigation was limited, yields were reduced to a considerable extent when water was withheld during warm weather in late April and May (treatment 5). Yields were reduced to a lesser extent when the same number of irrigations were applied but water withheld during the early part of the growing season (treatment 2) when plants were small and the weather generally cool.

Table 5.—*Effect of number and distribution of irrigations on the yield of Salt River canaigre grown near Queen Creek, Ariz., in 1955*

Dates and number of irrigations and root yields	Irrigations applied on plots [1]—							
	1	2	3	4	5	6	7	8
1954:								
September 24 [2]	X	X	X	X	X	X	X	X
November 18	X	-----	-----	X	X	X	-----	-----
1955:								
January 3	X	-----	X	X	X	X	X	-----
February 15	X	X	-----	X	X	X	-----	X
March 16	X	X	X	X	X	X	X	-----
April 5	X	X	X	X	X	-----	-----	X
April 25	X	X	X	X	-----	-----	X	-----
May 17	X	X	-----	-----	-----	-----	-----	-----
Irrigations applied after stand established ... number	7	5	4	6	5	4	3	2
Root yield [3] ... tons per acre	16. 0	15. 0	14. 7	14. 1	13. 8	13. 3	12. 7	10. 9

[1] An estimated 3 inches of water applied at each irrigation.
[2] September 24 irrigation applied immediately after planting.
[3] Values given are means of 4 replications; least difference necessary for significance at the 5-percent level is 2.8 tons per acre; coefficient of variability is 13.8 percent.

The results of two further trials were similar to those of the first, but the method of approach was different. In the later trials three basic levels of irrigation were selected—high, medium, and low—with the need for irrigation predicated upon readings of gage-type tensiometers installed in the plots. At each basic level three treatments were imposed: (1) Irrigation at the indicated level throughout the growing season until top decline; (2) irrigation withheld after the plants were up until the middle of February, after which irrigation was applied as needed; and (3) irrigation withheld after seed maturity, approximately April 15.

Because the acreage available for each of these trials was so limited, it was necessary to apply irrigation water by the basin method to plots 35 feet long and six 30-inch rows wide. An attempt was made to apply approximately 3 inches of water at each irrigation. It is probable that if applied by the furrow method in field-scale plantings where rows were long, heavier irrigations would occur under similar conditions of soil permeability.

The relatively high root yields observed where irrigation was restricted is surprising in view of the differences in top growth between the various treatments. Plants receiving no irrigation until February made appreciably less top growth than those irrigated. However, the plants receiving the later irrigations appeared to overtake the regularly irrigated plants rapidly after irrigation was resumed. In plots receiving a low level of irrigation, the plants were much shorter and produced considerably less seed than in plots receiving plenty of moisture. Top growth declined 10 days to 2 weeks earlier in plots receiving the last irrigation in April rather than in May.

Under soil conditions where canaigre has been grown experimentally in central Arizona, it is likely that root yields approaching the maximum can be obtained from crown plantings with 2 acre-feet of water. Trials with seed-planted canaigre, comparable to those described above, have not yet been completed. It is probable, however, that two additional irrigations may be required to achieve top yields from seed. It is often necessary to irrigate twice in order to get the plants established and to apply one extra irrigation at the end of the season because seed-grown canaigre matures up to 2 weeks later than that grown from crowns under conditions of adequate moisture.

Fertilizer Requirements

Repeated efforts have been made to develop information on the fertilizer needs of cultivated canaigre. Generally, the results of fertilizer trials have been inconclusive. However, in several tests where the fertility level of the soil was quite low, the response to commercial fertilizers was marked. In one trial, for example (table 6), the application of nitrogen as a sidedressing to seed-planted canaigre early in the first season of growth increased top growth and root yields greatly. Added increments of nitrogen gave still further yield increases. The addition of phosphorus with nitrogen stimulated yields to much higher levels. And, when these treatments were repeated during the second season of growth, yields were even greater. In another trial on poor soil, phosphorus alone stimulated both top growth and root yield somewhat, while nitrogen alone had a depressing effect. Combined applications of nitrogen and phosphorus resulted in lower yields than when phosphorus alone was applied.

In nearly every case where fertilizer trials with canaigre were conducted on relatively fertile soil, root yields have indicated no definite pattern of response to fertilizers and yield differences be-

Table 6.—*Effect of commercial fertilizers on root yield of canaigre after it was grown 2 years from seed on Vinton sand at Stanfield, Ariz., 1950–52*

Plots	Rate of fertilizer application		Mean root yield [1] in plots fertilized—	
	N	P	First year only	Both years
	Lb./acre	*Lb./acre*	*Tons/acre*	*Tons/acre*
1	64	80	12. 7	14. 5
2	32	40	12. 1	15. 1
3	16	20	10. 5	13. 4
4	64	0	10. 9	13. 9
5	32	0	9. 8	12. 8
6	16	0	8. 7	10. 2
Check	0	0	7. 5	----------

[1] Values given are means of 3 replicates. Yield differences among treatments were highly significant. LSD is 1.88 tons/acre.

tween treatments have not been significant. In one crown-planted trial, where canaigre had been grown during the two preceding seasons, nitrogen and phosphorus were applied alone and in combination at different rates. The results, as summarized in table 7, are inconclusive, but suggest the importance of phosphorus in the nutrition of canaigre, even in good soil.

TABLE 7.—*Yields of canaigre roots grown 1 year from crowns in a fertilizer trial at Queen Creek, Ariz., 1955–56*

Plots [1]	Rate of fertilizer applications [2]		Ratio, N:P	Mean root yield [3]
	N	P		
	Lb./acre	*Lb./acre*		*Tons/acre*
1	0	100		13. 6
2	100	200	1:2	12. 6
3	100	100	1:1	12. 5
4	200	200	1:1	12. 2
5	100	0		11. 8
6	100	400	1:4	11. 6
Check	0	0		11. 5
7	200	400	1:2	11. 5
8	200	100	2:1	11. 5
9	100	50	2:1	11. 3

[1] Listed in order of yield results.
[2] Fertilizer was applied as a sidedressing in February.
[3] Values given are means of 6 replicates. Yield differences among treatments were not significant.

The failure of canaigre to respond to the use of commercial fertilizers in most cases where applied is somewhat puzzling. It already has been pointed out, however, that canaigre is a deep-rooted plant, and it undoubtedly forages to a much greater depth in the soil than do potatoes. Whatever the actual nutritional requirements of canaigre may be, it is believed that certain components are removed from the soil by the crop to some degree and that the yield of the following crop of canaigre is reduced in consequence. This yield depression has been noted in several instances where canaigre followed canaigre and comparisons were possible.

Under commercial production canaigre would be likely to follow canaigre on the same soil in many instances. Two preliminary trials, conducted under such circumstances, were crown-planted in 1956 and 1957, respectively, after barnyard manure was applied at commercial rates to field plots. The plots were harvested after 1 year of growth. Yields from manured plots were greater than from the check plots, the difference being highly significant in one experiment. Efforts to develop information on the nutritional requirements of canaigre are being continued, including the effects of increasing the organic matter content of the soil through manures and crop residues and the addition of minor elements.

Cultivation and Weed Control

Preplanting irrigation to sprout and destroy weed seed and cultivation after each irrigation or rain are recommended for canaigre. These practices are particularly important with seed plantings, because canaigre seedlings grow very slowly during the first 2 or 3 months and compete poorly with weeds. Furthermore, canaigre seedlings appear to receive some stimulation in rate of growth following cultivation, probably due to increased soil aeration. Two to four cultivations may be needed before the plants become large enough to be injured, owing to leaves being snapped off by cultivating equipment. After that time the plants shade the ground well enough to discourage weed growth.

Preharvest weed control is likely to be a serious problem in weedy fields, especially where harvesting is delayed for some time after the tops die back (fig. 7). The last irrigation of the growing season should be applied while tops are still green enough to dry out the soil. Otherwise, puncturevine, purslane, knotweed, and other summer weeds rapidly cover the ground with a mat of growth that interferes with harvesting. Summer rains also provide favorable conditions for weed growth. Cultivation or spraying with a contact herbicide may be necessary to hold the weeds in check.

Where Johnson grass and Bermuda grass occur in abundance in canaigre fields, harvesting is difficult. The matted masses of roots of these weeds are almost impossible to separate mechanically from canaigre roots, requiring added hand labor and resulting in losses of roots. Canaigre should not be planted in fields infested with these weeds.

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Figure 7.—Canaigre field in July ready for harvest. Clean cultivation during early part of growing season and withholding irrigation after top decline begins promote weedfree harvesting conditions.

Diseases and Insects

Canaigre formerly was believed to be susceptible to very few natural enemies. However, more recent observations seem to indicate that the crop is host to several diseases and many species of insects. The most serious disease encountered thus far is leafspot, caused by either of two fungi, *Ramularia descipiens* and *Ovularia canaigricola.* The disease seldom strikes before the plants are in bloom. Usually the first lesions, which are circular in shape and 1 to 2 centimeters in diameter, appear in April at a few limited spots in the field (fig. 8).

Infection may become complete within a few days, soon defoliating the plants and terminating growth prematurely as leafspot did during several seasons in Arizona up to 1953. Accurate estimates on yield reductions due to leafspot have not been possible. It is probable, however, that root yields may be lowered as much as 25 percent under severe early attacks. Efforts since 1953 to determine effective control measures have been thwarted, due to the fact that attacks, if they occurred at all, have been too light to test the effectiveness of fungicides.

Seedling blight and damping-off have been serious enough at times to reduce seed-planted stands severely. Causes of these conditions have not been determined. Seed treatment, using various fungicide dusts, has not been effective in reducing seedling losses. A small amount of dry rot has occurred in stored root material, the cause of which is not known. Varietal differences appear to exist in susceptibility to storage rots. Fortunately, the most desirable wild varieties, from the standpoint of root yield and tannin content, seem to be the least susceptible.

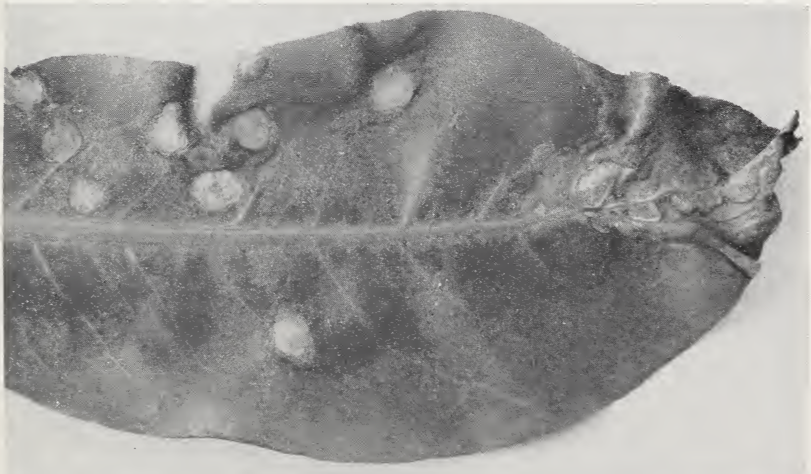

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FIGURE 8.—Canaigre leaf infected with leafspot disease in April. Severe attacks will defoliate plants and terminate growth. Effective control has not yet been determined. (Approximately natural size.)

A wide range of insect pests, common to other crops, have been observed on canaigre plants. Few, however, are known to damage the plants to any extent. Salt marsh caterpillars, *Estigmene acrea* Drury, at times have been extremely destructive to canaigre early in the season. Migrating from nearby cottonfields in countless numbers in October and November, they have completely destroyed seedling stands of canaigre and defoliated plants grown from crowns. Experimental plantings have been effectively protected by erecting aluminum foil barriers around the fields to exclude the caterpillars. Canaigre beetles, *Gastrophysa cyanea* Melsh, occasionally observed to be very destructive on wild canaigre plants, seldom have attacked cultivated canaigre and are easily controlled with insecticides. Other common insect pests, such as grasshoppers, aphids, thrips, and leaf hoppers, have attacked canaigre at times. A root borer, *Ophryastes tuberosus* Rec., has been observed to infest canaigre roots at many locations in the wild. However, damage by this insect in cultivated canaigre is exceedingly rare. The root-knot nematode, *Meloidogyne incognita*, was found on cultivated canaigre on sandy soil at Yuma, Ariz., in 1950. In greenhouse and field tests at Sacaton, Ariz., root-knot nematodes readily infested canaigre seedlings. No other cases of nematode injury to canaigre have been observed.

Harvesting

Canaigre is ready for harvest at any time after the tops have died completely back to the ground, as shown in figure 6. There are varietal differences in date of maturity, but the best locally adapted material matures in mid-June under favorable growing conditions. When grown from seed, top decline usually is delayed as much as 10 days or more. Lack of soil moisture or a severe attack of leafspot can terminate growth as early as April. Until the tops are entirely dead and dry, the skins of the roots are a dark brown and are tender and easily broken by rough handling during the harvesting operation. Damaged, immature roots do not store well, due to excessive loss of moisture and susceptibility to storage rots. Furthermore, the tannin content of roots does not appear to reach a peak until sometime after top decline. At maturity, the skins of the roots are very dark in color, almost black, and are tough enough to withstand some rough treatment without injury. Generally roots grown 1 year from seed are lighter in skin color and are somewhat more tender and easily damaged. Results of two time-of-harvest experiments are summarized in table 8.

Best harvesting results are obtained when irrigation is withheld after top decline has begun in May or early June, in order to dry out the soil and discourage summer weed growth. This is especially important where harvest is to be delayed for sometime after the tops are dead. A preharvest irrigation is usually necessary several days to a week in advance in order to facilitate digging. Canaigre tops are entirely dead and dry at harvesttime and separate easily from the dormant roots as they pass through the harvester. Under ordinary conditions it is unnecessary to pulverize dead tops with a roto-beater before digging.

Multiple-row combine harvesting equipment and bulk handling methods employed in potato harvesting undoubtedly can be used,

TABLE 8.—*Results of time-of-harvesting experiments of Salt River canaigre grown 1 year from crowns, at Tempe, Ariz., in 1953 and at Queen Creek, Ariz., in 1956*

Dates of harvest		Plant condition	Analysis of dry root material			
			1953 crop		1956 crop	
1953	1956		Tannin content	Extract purity	Tannin content	Extract purity
			Percent	*Percent*	*Percent*	*Percent*
May 1	May 10	Tops green, root skins tender.	32. 52	67. 86	32. 92	70. 06
June 1	June 8	Tops dying, skins tougher and darker in color.	34. 18	70. 11	33. 94	71. 28
July 7	July 9	Complete dormancy, skins hard, nearly black.	33. 86	68. 63	34. 62	67. 99
Aug. 6	Aug. 10	Sprouts forming at crowns.	35. 62	65. 41	36. 49	65. 22
Sept. 1	Sept. 7	Sprouts ½ to 1 inch long.	36. 12	63. 19	36. 28	65. 84
Oct. 1	---------	Sprouts 1 inch long, no plants up.	37. 28	65. 52	-------	-------

with only slight modification, for harvesting canaigre. Owing to the somewhat greater depth to which canaigre roots extend in the soil as compared with potatoes, digger blades must operate several inches deeper than for potatoes, with a consequent greater downward pull on the blade. Likewise, the quantity of soil that must pass through the separating mechanism is increased, adding to the load that the machine must carry. These two factors may require strengthening of the front end of certain makes of potato-digging machinery to be used for harvesting canaigre.

The development of canaigre harvesting methods has kept pace with the development of cultural practices. Up to 1950 three different makes of commercial potato diggers were used successfully in digging canaigre in Arizona and New Mexico. But the high labor cost and the physical effort required in the July and August heat to handpick the roots behind the digger prompted efforts to develop a combine harvester-type of machine that would be applicable to experimental plot work. Such a machine, designed in 1950 with the cooperation of E. N. Humphrey, then agricultural engineer with the Idaho Agricultural Experiment Station at Aberdeen, Idaho, was constructed by an Idaho potato harvester manufacturer. The single-row, power-takeoff operated canaigre harvester embodied mechanical principles included in standard potato-harvesting equipment and in addition possessed a very strong frame and a wide range of adjustment for experimental use. Alterations and improvements were made during the next 3 years (1951–54) with the cooperation of the Agricultural Engineering Division of ARS. The resulting two-wheeled, trailer-type machine has its own source of power for the

operation of the separating and hydraulic mechanisms. It can be pulled by a wide range of tractor equipment, and its great versatility enables it to be used in harvesting canaigre and other crops under a wide range of experimental conditions (fig. 9).

ROOT STORAGE

In a commercial production program, it is very likely that the bulk of canaigre roots harvested will have to be stockpiled for periods of 8 to 9 months. Harvesting probably will be limited to the first 2 or 3 months during the summer dormant season of the crop, in order to free the land for planting to another crop. Extraction plants, on the other hand, will be required to operate throughout most of the year. Practical, economical methods of bulk root storage will be required.

Various methods of fresh root storage have been investigated. These include storage in earth-covered pits and piles, in bins and bags under a roof, in unprotected heaps in the open, in brush- or hay-covered piles on the ground, and in low-temperature storage. The minimum physical requirements for satisfactory root storage appear to be simple: (1) Freedom from excessive harvest injury, (2) adequate aeration of the roots, (3) exclusion of large amounts of dirt and trash, (4) protection from excessive heat, and (5) protection from sunlight.

Storage of large quantities of roots in earth-covered pits or piles was entirely unsatisfactory. Aeration of the roots was prevented, resulting in the development of temperatures as high as 120° F. among the roots. In consequence, the overheated roots were killed and rendered unfit for processing. The extractable tannin content of roots thus overheated was reduced to approximately one-half the original level. When left uncovered, freshly harvested roots in the surface layers of the piles were killed quickly, owing to exposure

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FIGURE 9.—Harvesting canaigre with experimental canaigre harvester patterned after potato combine harvester. Machine is especially adaptable to digging small-scale experimental plantings.

to the sun. The dead roots soon dried out completely and became hard as wood, losing over one-third of their tannin content.

Roots held in cold storage (temperature, 45° to 50° F.; relative humidity, 75 to 90 percent) for a period of 8 months kept in excellent condition with no loss of tannin. Cold storage of commercial quantities of canaigre roots, however, would not be economically feasible. Roots placed in bins and sacks under a roof also stored in good condition for periods exceeding 1 year. For commercial quantities, however, the outlay for warehousing might prove economically impractical.

Freshly harvested canaigre roots have been stored successfully for periods up to a year in 20-ton piles on the ground and covered only with hay and brush to keep them shaded from the sun. When stored in that manner the temperature of the roots at the centers of the piles dropped quickly to around 70° F. and remained near that level, even on days when the temperature of the surrounding outside air exceeded 105°. Roots on the surface of the piles immediately under the hay covering remained undamaged. Some loss of moisture occurred in roots stored thus in piles but not enough to affect viability or processing. A small loss in dry-matter content also occurred, attributable to respiration. But there was little, if any, loss in tannin content. Parts of roots that had been badly mutilated during harvesting became hard and dry in storage. Roots that suffered little or no harvest injury remained sound and healthy. Rainfall sufficient to wet the roots to the centers of the piles appeared to do no damage.

Conceivably, the inclusion of large amounts of dirt and trash with the roots stored in very large piles could so restrict aeration that excessive buildup of heat could occur, resulting in serious damage to the roots. In the case of sugar beets, this problem has been successfully handled by forced aeration of large storage piles through vented tunnels passing underneath the beets. This problem has not yet been encountered with canaigre, because the large volumes of root material required for testing have not been available.

CANAIGRE AS A WEED

Canaigre is not mentioned in the weed manuals of any State, although at one time the plant grew wild from central Texas to the Pacific Coast on thousands of acres of land, which since have been brought under cultivation. In most instances canaigre has disappeared entirely from the land, unable to survive the onslaught of cultivation. A very few places are known in California, Arizona, and New Mexico, however, where canaigre has persisted as a mildly troublesome weed. In most of these cases the infestation consists of a few isolated plants that come up every year from roots so deeply placed in the soil that they escape serious injury from tillage implements. It is likely that these deeply buried roots were placed there by deep plowing or land-leveling operations when the land was first brought under cultivation. Canaigre is unable to establish new crowns at a level in the soil deeper than that of the parent crown.

Wherever canaigre has been grown under cultivation a heavy volunteer stand of plants usually has sprung up during the season after harvest. Volunteer plants arise from both seed and small roots that escape harvest. Work was begun in 1951 in an effort to develop practices for eradicating or controlling canaigre as a weed.

Very small seedling plants are easily killed by contact herbicides and by several formulations of 2,4–D and a number of related compounds. Although the tops of older seedlings and plants of vegetative origin were killed back to the ground by contact sprays, the roots were not affected and sent forth new top growth when conditions were favorable. Both the amine and ester forms of 2,4–D were only partially effective in killing canaigre roots at 4- to 6-pound rates of application during February and March. Certain other substances, such as CMU (3-(*p*-chlorophenyl)-1,1-dimethylurea) and maleic hydrazide, were much more effective, although not completely so, but the cost of materials at effective rates would be prohibitive.

A series of cultural treatments, alone and in combination with 2,4–D, was imposed in 1954 on a 6-acre field badly infested with volunteer canaigre after two experimental crops had been harvested. Cultural treatments included continuous fallow, cotton, alfalfa for hay, corn, barley, barley and corn double-cropped, and a winter green manure crop (papago peas) followed by corn. After three crop years the amount of canaigre survival in the cotton plots was almost none. Barley, with 2,4–D sprayed at a 4-pound rate at jointing time, also reduced survival of canaigre to practically nothing. Corn alone or with a winter cover crop was relatively ineffective, as was alfalfa for hay. In the fallow plots many canaigre plants survived repeated applications of 2,4–D.

These results are borne out by observations made on private land where heavy canaigre infestations existed following the harvest of production acreage in 1951–53. Canaigre has persisted in alfalfa for hay and to some extent in citrus groves where deep tillage is impossible. But where cotton has been grown continuously, canaigre has disappeared entirely without any special effort being made to eradicate it.

CANAIGRE BREEDING

The primary objective of the canaigre breeding work has been to select or breed high-yielding canaigre lines that have high tannin content and good root size and shape. Many other important factors, such as disease resistance, root storability, and seed production, are also considered. The breeding program has made use of reproduction by both seeds and crowns.

Wild collections of canaigre roots from all over the Southwest have been grown under uniform irrigated conditions and data obtained on growth and vigor, disease resistance, seed set, yield, root size and shape, and other factors. Samples of each collection have been submitted to the Eastern Utilization Research and Development Division for analysis. A wide variation has been noted between canaigre from different locations. Root size, percent tannin, and extract purity of a few of the collections are given in table 9.

TABLE 9.—*Root size and percentage of tannin and of extract purity of canaigre collected in various locations when grown under irrigation at Mesa, Ariz.*

Plants collected from—	Root size		Tannin content (dry-weight basis)	Extract purity
	Length	Diameter [1]		
	Inches	*Inches*	*Percent*	*Percent*
Salt River (Mesa, Ariz.)	3–7	1–1¾	35. 5	62. 7
Do	3–7	1–2	37. 7	63. 6
Do	3–7	1–1¾	32. 5	64. 1
Do	3–8	1–2	37. 5	66. 0
Do	3–7	1–2	34. 3	63. 2
Sacaton, Ariz	4–7	1½–3	35. 3	62. 8
Tucson, Ariz	3–4	1½	33. 4	65. 2
Do	3–5	1–1½	39. 3	66. 7
Higley, Ariz	9–18	2–3	29. 3	56. 3
Deming, N. Mex	6–8	1½	30. 5	57. 2
Whitewater, Colo	6–10	1	4. 7	12. 6
Bedrock, Colo	4–8	1½	20. 4	44. 6
Colton, Calif	4–6	1	30. 6	57. 6
Littlerock, Calif			34. 4	62. 4
Overton, Nev	6–10	½	24. 7	50. 7
Bluff, Utah	6–11	1½	18. 0	48. 5
Hite, Utah	4–9	1½–2	30. 0	54. 8
Balmorhea, Tex	3–8	1–2	13. 9	40 9
Sierra Blanca, Tex	4–14	1–1½	21. 8	49. 8
Van Horn, Tex	4–7	1–1½	11. 8	31. 3

[1] Range (or average in fairly uniform roots) of the diameter of root 2 inches from the crown.

Many collections included a number of plants each and selections were made of the more desirable roots that have been increased vegetatively. These vegetative lines were further evaluated in replicated yield trials. As a result of these trials, a number of higher yielding lines that have good root shape and contain from 34 to 39 percent tannin are being increased. A number of these better lines were collected along the Salt River near Mesa, Ariz. Extract purity, although not stressed in the selection program, ranges from 64 to 66 percent in these lines. The color of a cross section of the roots has been used as a general guide in selecting the higher tannin-containing roots. Roots with a slightly pink color have had a higher tannin content than those with a predominantly yellow color. The yellow roots are normally quite low in tannin. Color gradations within the pink range are not accurate for predicting the tannin content.

The amount of seed produced between collections and selections varies to a great extent. Some lines, particularly the Salt River material, produces very little seed, which shatters easily. A number of lines set large quantities of seed that do not shatter until well after maturity. Seed-planted canaigre from various sources has been tested. From most sources the variability in size (fig. 10) and in tannin content of seed-planted roots has been quite high as com-

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FIGURE 10.—Canaigre seedlings from a section of row thinned to 4 plants per foot, showing the variability within a single collection when grown from seed.

pared to roots from crown plantings. None of the plants from seed tested in such trials has been equal to the better vegetative lines tested in crown plantings. Seed-planted trials will be continued to test existing seed stocks and new lines developed in the breeding program.

Another important part of the canaigre breeding program has involved inbreeding, crossing, and selection. Canaigre, because of its heterozygous nature, generally has been extremely variable when grown from seed. Inbreeding, which has been carried on to produce plants that are much less variable when grown from seed, has caused a decrease in vigor in most cases. When more homozygous lines are developed, it should be possible to develop a hybrid canaigre that could be grown from seed, since canaigre, due to its protogynous nature, is largely cross-pollinated. Distinct genetic markers have not been found to determine accurately the amount of crossing; however, two vegetative lines with different root sizes and color have been grown in alternate rows for seed production. By classifying the roots grown from seed of these lines, it was estimated that 87 percent crossing occurred in one of the lines. This amount of

crossing would be adequate for hybrid seed production on a field scale.

Many crosses have been made between plants that have a high tannin content, desirable root shape, or good seed production. Due to the extreme variability in most canaigre, the progenies have been quite variable and selection has been possible in the first generation. A large number of seeds may be obtained in most crosses; therefore, it is possible to select from a fairly large population. Selections are made when the roots are dug, and these selections are then replanted as crowns the following season for further evaluation as seed or vegetative lines. A number of these selections, along with selections from the various canaigre collections, are being evaluated in both the seed- and crown-planted phases of the breeding program.

POTENTIAL CANAIGRE PRODUCTION AREAS

Canaigre has a wide range of adaptability as a wild species and has survived subzero temperatures under cultivated conditions in the high plains area of Texas and New Mexico. However, at elevations over 4,000 feet above sea level, the winters are usually cold enough to retard plant growth and reduce root yields. Consequently, commercial production is likely to be restricted to the warmer irrigated valleys of the southern tier of States bordering on Mexico. Those areas that have sufficient acreage under cultivation and with conditions of soil, water, and climate favorable for canaigre include the following:

1. Antelope Valley, Calif.
2. San Joachin Valley, Calif.
3. Southern Yuma County, Ariz.
4. Salt River Valley and Pinal County, Ariz.
5. Cochise County, Ariz.
6. Upper Rio Grande Valley, Tex., and N. Mex.
7. Winter Garden area of southern Texas.[2]

Many smaller irrigated areas in these States, as well as in Nevada and Utah, also have environmental conditions favorable for canaigre, but acreages are not large enough to support processing plants. It is estimated that an extraction plant would require the production of 4,000 to 5,000 acres of canaigre each year for efficient operation. Hauling canaigre roots long distances to a processing plant would not be economically feasible, since only about 10 percent of the weight of the roots is tannin.

ECONOMIC ASPECTS OF CANAIGRE PRODUCTION

At the present time (1958) no market for canaigre exists and there is no commercial production of the crop. In the event that a national emergency precipitates an immediate demand for canaigre production, it would require up to 100,000 acres of the crop to supply the Nation's needs for tannin. At least 3 to 5 years would be

[2] High incidence of leafspot disease and preharvest root decay may render this area unsuitable for canaigre, unless controls can be developed.

required to increase existing seed stocks sufficiently to plant that acreage. It is more likely, however, that if commercial production of the crop develops, it will start slowly and attain its ultimate level in competition with other sources of tannin. Consequently, canaigre probably will not be a high-value crop, but instead may be a fairly moderate but reliable source of income to the grower.

The probable price level for canaigre tannin could be expected to follow closely the market prices of imported tannin extracts under normal conditions. But it is not known as yet what the cost of processing canaigre industrially will be, if newly developed methods of tannin extraction are used. Consequently, it is not possible at this time (1958) to estimate the returns growers might expect from the crop. However, under present farming conditions and on the basis of information developed on the cultural requirements of canaigre, Salt River Valley growers probably would be able to deliver roots to a local processing plant at a reasonable profit for about $19 per ton.

SUMMARY AND CONCLUSIONS

Canaigre, a wild perennial herb native to much of Southwestern United States and Northern Mexico, was known by natives and early white settlers as a source of tannin for making leather. Commercial efforts to exploit wild stands of canaigre for that purpose in the 1880's and 1890's failed, owing probably to plentiful supplies of cheaper materials from other sources. Depletion of existing domestic tannin supplies and foreign resources gave rise to a program of research for the development of canaigre as a domestic source of tannin, beginning in 1937. Cooperating in the program, still in progress, are the Crops Research Division of the Agricultural Research Service, which conducts research on all phases of development of the plant as a cultivated crop, and the Eastern Utilization Research and Development Division, which conducts research on the processing and utilization of canaigre in leather manufacture.

In the 20 years covered by this report, the wild population of canaigre has been surveyed and representative plants from scores of locations have been grown for observation and selection of breeding material. Superior vegetative lines, yielding 15 to 20 tons of roots per acre and having a tannin content up to 38 percent or above, have been isolated and are being increased. Production of the crop from seed is an ultimate goal of the breeding program, although at present it is not feasible, owing to the mixed genetic behavior of the plant and to low yields of roots having a low tannin content.

Test plantings have been made in most of the Southern and Southwestern States to determine the regional adaptability of canaigre as a crop. It does not appear to be adapted to Southeastern United States. The best results were obtained in the hotter, more arid sections of Arizona, New Mexico, and Texas.

Work on development of cultural practices and production methods was conducted mainly in Arizona. Canaigre culture is similar to that of potatoes and adaptable to the same machinery. The crop is best adapted to light sandy loam soils and cannot be grown suc-

cessfully without irrigation. Satisfactory yields on good soil may be attained with 6 to 8 irrigations, totaling around 2 feet of water, applied mostly in March, April, and early May.

Crowns are planted in ridges in October for highest yields. Later planting results in reduced yields. Commercial fertilizers have not given increased root yields except in soils low in fertility, while increased yields have followed the application of manure, even on fertile soil. Crop rotation studies including canaigre have not yet been undertaken. Early-season growth is slow and clean cultivation necessary until January. No difficult insect control problems have developed. No effective control has been found for leafspot, a fungus disease that has defoliated the crop prematurely in some years.

Canaigre plants normally die back to the crowns in June, after which the roots are mature. Earlier harvest than June results in lower root yields, reduced tannin content, and poor storability. Several standard makes of potato digger have been used to dig canaigre. A special experimental combine harvester was developed and used successfully for harvesting both seed- and crown-planted canaigre. Harvested mature roots have been stored successfully in large piles for periods up to 1 year without loss of tannin when the roots are covered with loose hay or brush to protect them from the sun. Other methods of storage of large quantities either were not economically feasible or resulted in spoilage.

Volunteer canaigre plants usually appeared in large numbers during the next season after harvest of the crop. The use of herbicides to eradicate volunteer stands was only partially successful. Volunteers persisted for years without reduction in numbers where the crop was followed by alfalfa for hay. Cotton for 3 years following canaigre reduced survival counts to almost none.

On the basis of accumulated knowledge of canaigre cultural requirements and production costs on other crops, it is estimated that canaigre can be grown and delivered to local extraction plants in the Salt River Valley of Arizona for about $19 per ton.

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